THERMAL BEHAVIOUR OF CABLES INSTALLED VIA DIRECTIONAL DRILLING

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ABSTRACT

The permitted ampacity for a MV-cable is currently based on tables [1] which hold into account the placement of the cables and derive the permitted load. These tables are limited to the most used placement setups and load cycles.
In recent years it is also possible to simulate the core-temperature of the MV-cable by using simulation software. This software can hold into account more complex burying principles and can simulate the temperature based on different and more complex load cycles. Eandis uses this software to simulate the thermal effects of cables installed at greater depths, using directional drilling. Due to the greater burying depth, the software indicates that the ampacity of the cable is decreased significantly (up to 50% in some cases).
By using a fibre optic (FO) cable and measuring device, the theoretical results, as simulated by the software, can be compared with real-time measurements.

INTRODUCTION

When cables need to cross natural or man-made obstacles (f.e. cross-roads, rivers, highways, ...), Belgium DGO (Distribution Grids Operators) use directional drilling methods. As a result, the cables are installed on greater depths (up to 25 m deep).
The typical lay-out of directional drilling is as follows:

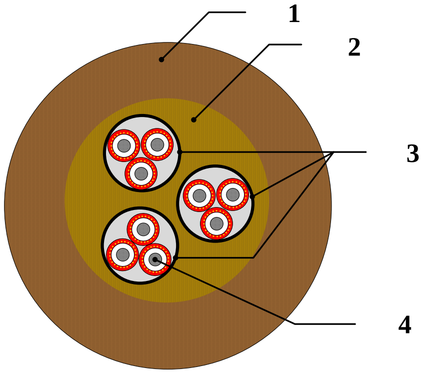


Figure 1: Typical lay-out of a typical directional drilling

With:
1) The soil, as naturally present.
2) A pumpable grout to ensure the mechanical stability of the borehole (for example: bentonite).
3) PVC ducts.
4) 3 single-core MV-cables type EAXeC(e)WB [2] per PVC-duct.

Based on software simulations of the thermal behaviour of cables installed via directional drilling, additional countermeasures were required in order to ensure the ampacity of MV-connections. Eandis took following countermeasures:

- Selection of a higher cross-section of MV-cables in the directional drilling.
- Separation of boreholes (distance between 2 boreholes: min. 5 m).
- Separation of the three single core MV-cables in the directional drilling.
- Filling of the PVC-ducts with thermal materials (for example bentonite).

This results in an additional cost for the DGO.
In order to justify these additional costs and to compare the theoretical temperature results with measured values, a Belgian group of DGO have made measurements along the cables using FO cables .

THEORETICAL STUDY USING SOFTWARE SIMULATIONS

The software used for these simulations is Cymcap.
This software calculates the ampacity of the MV-cable based on international standards [2].
The standard defines 4 different temperature zones (figure 2):

- T_1 = Temperature insulation between conductor and copper wires (screen).
- T_2 = Temperature insulation between the filling elements, insulation tapes and copper wires (screen).
- T_3 = Temperature insulation of the outer sheath
- T_4 = Temperature insulation of the ground

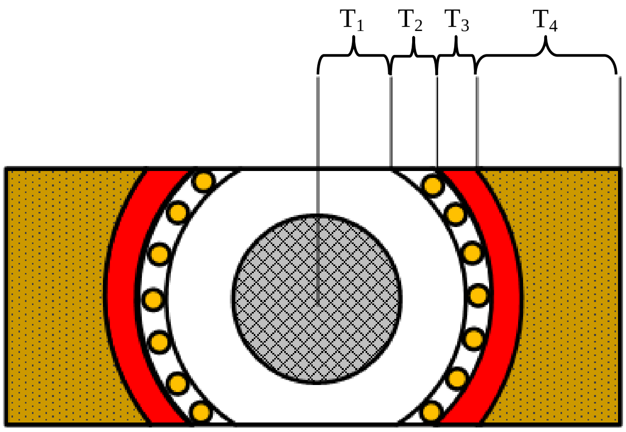


Figure 2: Profile of a MV-cable and resulting thermal resistances.

Between the different temperature zones, heat conversions take place. These heat conversions limit the amount of current that can be transmitted through the cable. The formula to determine this current (for buried cables where partial drying-out of the soil does not occur, according to [3]) is:

$$I = \sqrt{\left(\frac{\Delta\theta - W_d\,(0.5\,T_1 + n\,(T_2+T_3+T_4))}{RT_1 + nR\,(1+\lambda_1)T_2 + nR(1+\lambda_1+\lambda_2)(T_3+T_4)}\right)}$$

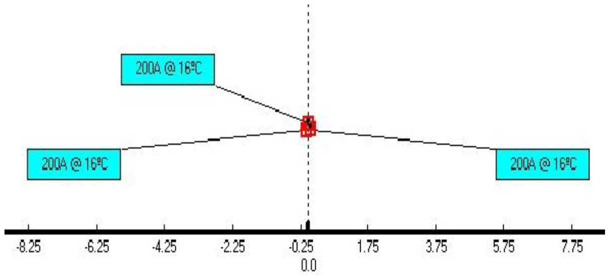
With:

- $\Delta\theta$ = the conductor temperature rise above the ambient temperature (K).
- R = the a.c. resistance of the conductor per unit length at max. operation temperature (Ω/m).
- W_d = dielectric loss per unit length for the insulation surrounding the conductor (W/m).
- n = the number of load-carrying conductors (for single core cables = 1).
- λ_1 = the ratio of losses in the metal sheath to total losses in all conductors in that cable.
- λ_2 = the ratio of losses in the armouring to total losses in all conductors in that cable.

For the theoretical model following presumptions were made:

- Load: 200 A, permanent load.
- Burying depth: 11 m
- The PVC ducts are laid in trefoil with one cable placed in each duct (filled with air).
- Initial soil temperature is 5°C.
- The thermal resistivity of the ground in wet state is 0,64 °Cm/W
- The copper screens of the MV-cables are connected with the ground on both ends.

Based on these presumptions following results were obtained:



Phase	Temperature outer sheath [°C]	Ampacity [A]
L1	16	200
L2	16	200
L3	16	200

Table 1: Summary theoretical results

PRACTICAL OBSERVATIONS BY MONITORING USING FIBRE OPTICS (FO) CABLES

Used Components

In order to measure the temperature profile along a MV-cable , it is necessary to install in the vicinity of the cable a DTS (Distributed Temperature Sensing) cable, a FO. Since there is no MV-cable with an integrated FO cable for a tension level of U_0/U 8,7/15 kV available, Eandis uses a separate FO cable which is placed along the MV-cable.
The FO cable is attached to the outer sheath of one of the single core MV-cable with cable ties. The assembly is pulled into the PVC duct.

Figure 3: FO cable used in practical tests

During the pulling process, the forces, exerted on the cables, can be very high. Since the maximal tensile (1500 N) and crush strength of the FO cable are limited, there is a realistic chance of damaging the delicate FO cable.
As measuring device, the AP Sensing Linear Power Series N4685B was used.

Temperature measurement via FO-cable

Temperature measurements via FO-cables are carried out by injecting a laser pulse in one of the glass fiber cores.

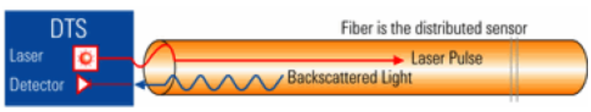


Figure 4: principle of temperature measurement via FO cables

Due to the injected laser pulse, light is backscattered to the source. The typical waveform of this backscattered light is as follows:

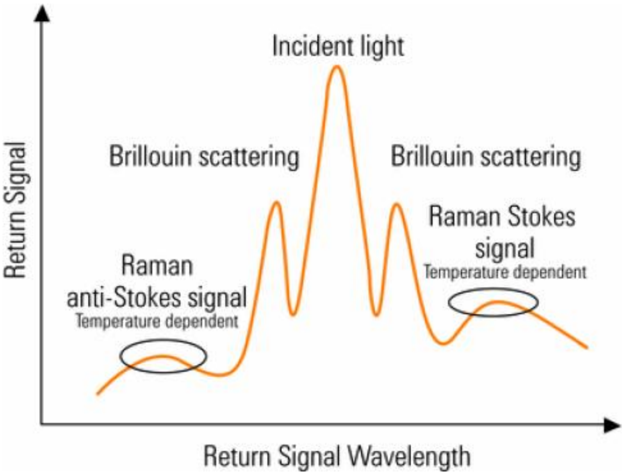


Figure 5: Typical waveform of the backscattered light

In this waveform, the Raman Stokes and Anti-stokes signals are temperature dependent.
The temperature of a specific cable length can be obtained from the amplitude of the Raman stokes and anti-stokes signal and the time that has passed since the injection of the original laser pulse.
The declared accuracy of the measuring device is ±0,6°C and 1 m.

Validation of the FO cable

The declared accuracy of the system was subjected to a laboratory calibration test.
The FO cable was placed inside an oven and the temperature was gradually raised to 100°C. The measured values were also compared with thermocouples measurements.

Based on the calibration results, we were able to conclude that the precision of the FO cable is off ± 2°C for a temperature in the range of 10°C - 40°C and ± 1°C for T°C between 40°C and 90°C. These results are valid for an exposed FO length of at least 1m. Temperature measurements along an overheated length smaller than 0,5 m (e.g. joint) could have a precision of only 50% of the real temperature. .
For an external temperature of 100°C, the external FO cable will reach the 85°C in less than 3 minutes and the temperature variations are highlighted by measurement in a few seconds. We conclude that the FO has a very small thermal inertia.

Field test-setup

The field setup at Eandis is as follows :

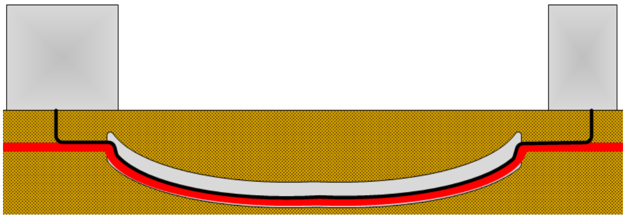


Figure 6: Typical field set-up

The measuring device is placed in a cabinet (indicated left on figure 6). In the cabinet (detail, see figure 7), additional component are installed: a LV-connection and meter; a no-break system to ensure that the measurements can continue in case of a LV-interruption; a GPRS-modem for remote access; a heating device to avoid internal condensation.
From the cabinet, the FO cable is attached to the MV-cable by cable ties and is pulled into the directional drilling. At the end, the FO cable resurfaces into a second cabinet (right side of figure 6). In this cabinet an end termination is installed on the cable to avoid additional reflections in the cable.

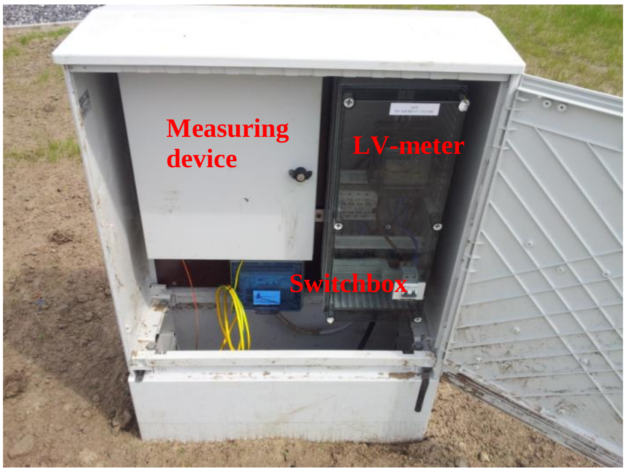


Figure 7: Detail of the departure cabinet (UPS not foreseen in this unit)

On the first practical observation site, two FO cables were placed into PVC ducts. One PVC duct was air filled, the other one was filled with bentonite, which has better thermal conductive properties than the surrounding soil.

Results

During the monitoring period a maximum load of 318 A was registered on the EAXeCeWB 1x400/25 mm²cable.

The maximum registered temperatures are:

- In the directional drilling without bentonite (probably filled with water and mud): 14°C for a load of 218 A.
- In the directional drilling with bentonite: 13°C for a load of 318 A.

The registered temperature profile (T = f(length, time)) is displayed below:

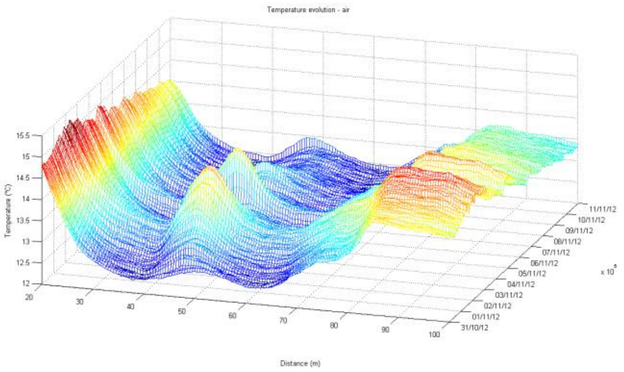


Figure 8: Registered temperature profile (T = f(length; time))

Based on this temperature profile following conclusions can be drawn:

- The temperature inside the directional drilling is lower than the temperature at "normal" burying depth (0,8m). Possible explanations for this phenomenon are lower and more stable ground temperatures at greater depths, and the presence of ground water which moves through the PVC ducts and cools down the cable.
- Local hotspots can occur. In this case the "hot" spot was located at the deepest point of the directional drilling.
- The temperature at depth remains stable and independent of the load while the temperature at normal depth varies according to the load. This is possible due to the high thermal inertia of the ground at greater depth.
- Even though the temperature in both drillings are similar, the one filled with bentonite, has a smoother temperature profile than the one filled with air (or with water and mud). This could be due to an uniform evacuation of the heat by the bentonite along the profile. No high or critical temperatures were registered during this period.
- The measured temperatures correspond with the simulated values. A comparison between these temperatures is listed in the table below:

Load	200 A
Simulated temperature (conductor)	16°C
Simulated temperature (outer sheath)	15°C
Measured value	14,2°C

Table 2: Comparison between simulated and Measured values

CONCLUSIONS

For crucial MV-connections (for instance to connect decentralized production units) temperature monitoring of MV-cables can be an asset.

Due to the limited mechanical properties of a separate FO cable, the risks of damaging or breakage of the FO cable is quite high. In accordance with HV-cables, a MV-cable with integrated FO cable provides additional mechanical security and is recommended to install in directional drillings. However, to this date no MV-cable with an integrated FO cable for tension level of U_0/U 8,7/15 kV are available on the market.

Separate FO cables provide a sufficient high level of precision and have a very low thermal inertia.

Based on the low loads, registered during the monitoring periods, the theoretical models are consistent with the practical measurements.

REFERENCES

[1] HD 620 *Electric cables - Calculation of the current rating - Sections on operating conditions* (type 10 B-B)

[2] IEC 60287; IEC 60228; IEC 601042; IEC 60853

[3] IEC 60287-1-1 *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*